CLIVAR

The Principal Research Areas

D1: The North Atlantic Oscillation

Goal:
Improving the description and understanding of decadal ocean and atmosphere variability in the North Atlantic region involving the North Atlantic Oscillation.

Introduction

The North Atlantic Oscillation (NAO) is a large-scale alternation of atmospheric mass with centres of action near the Icelandic low-pressure region and the Azores high-pressure region. It is the dominant mode of atmospheric behaviour in the North Atlantic sector. The NAO is most pronounced in winter but detectable as a characteristic pattern in all months. The winter NAO exhibits variability on time scales from a few months through several decades in the instrumental record, including an evolution from quasi-biennial predominance in the last century to increasing decadal and interdecadal prominence through this century (Fig. 1).

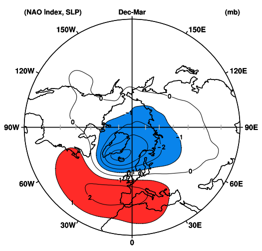


Fig. 1a: Observed Dec-March change in SLP associated with a 1 standard deviation change in the NAO index (after Hurrell, 1995, Science, 269, 676-679).

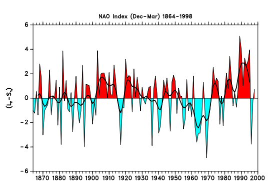


Fig. 1b: Winter (December to March) index or the NAO based on the difference of normalized pressure between Lisbon, Portugal and Stykkisholmur, Iceland from 1864 to 1995. The SLP anomalies at each station were normalized by division of each seasonal pressure by the long-term mean (1864-1995) standard deviation. The heavy solid line represents the meridional pressure gradient smoothed with a low pass filter with seven weights (1,3,5,6,5,3, and 1) to remove fluctuations with periods less than 4 years (after Hurrell, 1995, Science, 269, 676-679).

Scientific Rationale

There is a 4-fold justification for studying the NAO within CLIVAR:

1. The NAO controls the atmospheric factors which effect change in the ocean, i.e. heat flux, wind speed and direction, and P-E (precipitation minus evaporation).
2. The ocean is observed to have low-frequency basin-scale circulation and property distributions that vary with the atmospheric NAO, and are potentially indicative of a coupled North Atlantic Atmosphere-Ocean Oscillation.
3. The NAO seems to have made the largest individual contribution to the observed hemispheric warming trend in winter, though we cannot yet tell whether this change owes anything to human activity.
4. The amplitude of its decadal / interdecadal variability appears to be increasing with time. CLIVAR efforts to understand the workings of the NAO will include improved monitoring, process studies and modelling of the coupled ocean-atmosphere system.

Decadal Predictability of North Atlantic SST's ?

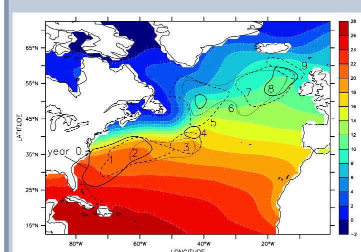


Fig. 2: Correlation between low frequency fluctuations in local wintertime SST and low frequency fluctuations in wintertime SST averaged over the region 80-60^{o}W, 31.5-38.5^{o}N (the vicinity of Cape Hatteras (VCH)) as a function of lag. The contours pick out the regions where lag-correlation with VCH is maximised. The numbers next to each contour indicate the lag in years. In all cases SST in the vicinity of Cape Hatteras is leading. The contour value is 0.8 for lags of 0 to 8 years and 0.75 for the lag of 9 years. The contours are superimposed on the SST files averaged over all winters between 1945 and 1989 (contour scale in ^{o}C) (from Sutton and Allen, 1997, Nature, 388, 563-567).

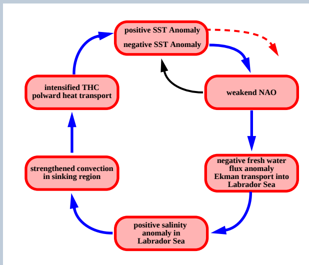
Mechanisms for decadal modes in the North Atlantic

The NAO - A coupled mode or uncoupled mode?

- An internal atmospheric mode without surface feedback cannot explain the observed decadal variability of the NAO pattern.
- There is growing observational and modelling evidence to suggest that decadal variability over the northern ocean basins is governed by the coupled ocean-atmosphere system, including processes which might determine longer period fluctuations in the NAO.
- Different hypotheses to explain the NAO exist. Note, that the following table does not summarize all scientific hypotheses

Paradigma for interdecadal variability	atmospheric and oceanic peak	panoceanic connection
noise driven ocean oscillator (Delworth et al., 1993, Griffies and Tziperman, 1995)	no atmospheric feedback not crucial	no different time scales of Pacific an Atlantic
coupled mode (Timmermann et al., 1998, see below)	yes memory resides in the ocean	yes atmosphere is the coupling device
atmospheric mode (James and James, 1989)	yes internal atmospheric memory	yes forcing oceans with one freqency

Table 1: Different hypotheses to explain the interdecadal variability of the NAO (from Timmermann, et al., 1998, J. Climate, 11, 1906-1931)



A coupled mode of the NAO as simulated by Timmermann et al., 1998, J. Climate, 11, 1906-1931) (see text).

The NAO: - The Role of the Ocean -

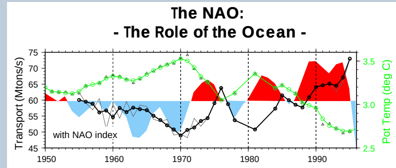


Fig. 4: Ocean temperatures and transports related to the NAO: Low-passed winter NAO index (Hurrell, 1995, red=high, blue=low), the variation in the temperature of deeply convected water in the Labrador Sea (green line, right scale) and the variation in eastward baroclinic transport of the Gulf Stream/ North Atlantic Current, as indexed (heavy black line, left scale) by potential energy anomaly differences between the Labrador Sea and Bermuda (an oceanic analogue of the atmospheric NAO index).
The warming temperatures before 1970 (low NAO index) and cooling thereafter (high NAO index) are also reflected in subpolar SST. These changes are the underlying cause of the Cold Ocean part of the "Cold Ocean - Warm Land" pattern in the Atlantic sector in the past 25 years. Oceanic transports appear to lag the NAO by 4-5 years, and decline with the warming Labrador Sea (and general subpolar SST) and declining NAO index of the 1950's and 1960's. The oceanic transports rise again with the cooling Labrador Sea (and general subpolar SST) and strengthening NAO index of the 70's, 80's and 90's. The 0.8°C temperature range of this large pool of subpolar water, and the fluctuation range of more than 30% in circulation intensity are some of the indications of a powerful participation of the ocean in this North Atlantic Atmosphere-Ocean Oscillation (from McCartney, pers. communication).

Sustained Observations

An "NAO Array"

Goal:

To provide high time-resolution full-depth hydrography at a few key locations, analogous to the old OWS's (or the continuing Bermuda and OWS M time-series) to supplement the sparser time resolution of XBTs, profiling floats and intermittent hydrographic sections.

Why ?

To study the slow covariant evolution of ocean signals, a sparse inter-gyre network of moored deep-parked profiling CTDs, can assess the evolution of temperature and salinity content in the mode water and thermocline, as well as describe the seasonal capping of the system.

A total of seven deep-moored profiling CTDs, illustrated in Fig. 3 is suggested:

(i) The existing BRAVO site in the central Labrador Sea. Though this site lies east or southeast of the maximum winter heat flux, the merit of extending an existing long time-series is the deciding factor in a study which depends so strongly on identifying decadal change.

(ii) Assuming Bermuda (Station S) continues to be ship-based, a second moored profiler on the Slope north of the Gulf Stream (say in 4000m southeast of Woods Hole) can serve as a complement. This would simultaneously monitor the evolution of the deep water brought south in the DWBC and provide a direct measure of the expected response in terms of the changing dynamics and stability of the eastward flowing Gulf Stream jet.

(iii) A third moored profiler at the offshore side of the DWBC south of Cap Hatteras to investigate the phase-lag of DWBC signals, and the waxing and waning of the LSW signal for comparison to that north of the Stream.

(iv) A ship-based Canaries series to couple with the Bermuda site (also ship-based) to provide a subtropical gyre index, a record of subducting watermass changes in the eastern subtropics, and a measure of the expansion and contraction of LSW influence on Upper North Atlantic Deep Water.

(v) Since the circulation bifurcates at the tail of the Banks, the subtropical gyre east of Newfoundland does not track the GS well. To monitor the split between the Gulf Stream recirculation and the Azores Current versus the northward then eastward North Atlantic Current (NAC), two further moored profilers, one in the central Newfoundland basin, the other near the Grand Banks are proposed. Again, analogous to the Bermuda-Slope pairing ((ii) above), this would provide an NAC Index as well as recording watermass property changes in the southward-flowing DWBC.

(vi) A further moored profiler is suggested for the Rockall area of the Eastern Atlantic, to index the baroclinic gyre between there and BRAVO and to characterise the warm water flowing north in the transformation pipeline west of Ireland.

(vii) The final moored profiler is suggested to lie at the East Slope of Greenland, placed to sample the Irminger Current as the watermass entrained by the Denmark Strait overflow.

A tentative NAO Array

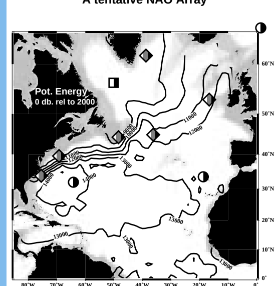


Fig. 3: Potential energy anomaly 0 - 2000 db for the climatological average North Atlantic, a baroclinic transport streamfunction for that layer relative to 2000 db. The positions of a Dec-Cen "NAO Array" of moored profiling CTDs are indicated by different symbols. In Fig. 3 the time history of baroclinic transport from time-series at two of these locations is shown. A complete array would add tropical subtropical sites south of 30^{o}N to include the whole ocean decadal variability implied by the coherent SST whole-ocean fluctuations described by Kushnir (1994, J. Climate, 7, 142-157) and Sutton and Allen (1997) (see figure 2), and be co-ordinated with the CLIVAR Programme on American Monsoons (G3) and Tropical Atlantic Variability (D2).

Impacts

The NAO and northern Cod

NAO Winter Index

strongly positive	strongly negative
⇓	⇓
cold air, strong winds	warm air, weak winds
⇓	⇓
large ice cover	small ice cover
⇓	⇓
large C.I.L	small C.I.L
⇓	⇓
low surface and bottom temperature	high surface and bottom temperature
⇓	⇓
low surface summer salinity	higher surface summer salinity
⇓	⇓
poor recruitment and growth	good recruitment and growth

A summary of consequences of strongly positive or negative NAO index on the recruitment and growth of northern Cod; from Mann and Drinkwater (1994). C.I.L is the 'cold intermediate water' on the Labrador Shelf.

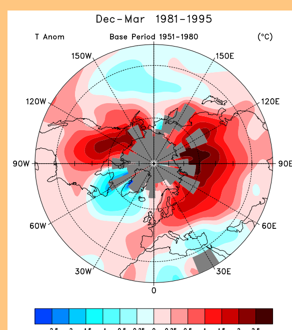


Fig. 5: Observed Dec-March surface temperature anomalies associated with a high NAO index; the period 1981-1995, when the NAO was high, relative to the period 1951-1980, when the NAO was low (after Hurrell, 1996). The temperature data consists of land surface temperature blended with SST data (Jones and Briffa, 1992, The Holocene, 2, 174-188).

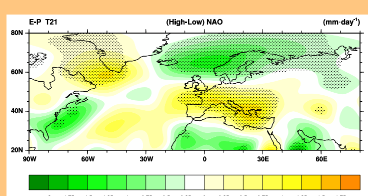


Fig. 6a: Above: Precipitation anomalies associated with the NAO; E-P is plotted, computed as a residual of the atmospheric moisture budget using ECMWF global analyses, for high NAO index minus low index winters (see Hurrell, 1995, Science, 269, 676-679).

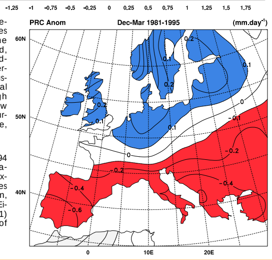
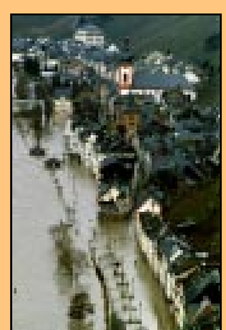


Fig. 6b: Right: 1981-94 average precipitation anomalies expressed as departures from 1951-80 mean, from station data in Eischeid et al. (1991) data set (courtesy of J. Hurrell)



Flooding episodes (here Mosel Valley, Germany, January 1997) can affect part of western and central Europe, esp. during extreme phases of the NAO (© W. Baum, dpa, 1997).

Ongoing activities

Atlantic Climate Change Experiment (ACCE)

The WOCE Atlantic Climate Change Experiment (ACCE) observational program began in October, 1996 with float deployments continuing through late 1998. It consists primarily of several basin-wide hydrographic sections, an extensive deployment of profiling autonomous (PALACE) floats, and a deployment of acoustically tracked (RAFOS) floats within the North Atlantic Current and its extension. The hydrographic sections were carried out in 1996 and 1997, with some further repeats along 24^{o} and 48^{o}N. We expect data from the floats to slowly decrease in volume but to continue through early 2000.

Although the ACCE profiling float data set will be the most extensive every collected, it will still not provide the basin-wide coverage envisioned for CLIVAR and GODAE. The one region where the proposed coverage is attained in ACCE is the sub-polar North Atlantic. In the analysis of ACCE there are plans to carry out a number of assimilation case studies using the float data set. However one must recognize that where the data coverage is highest is also the region where the expected eddy horizontal scale is of order 10-20 kilometres.

Cross linkages within other CLIVAR PRA's

This research project is closely related to the following CLIVAR PRA's:

D2
Tropical Atlantic Variability

D3
Atlantic Thermohaline Circulation